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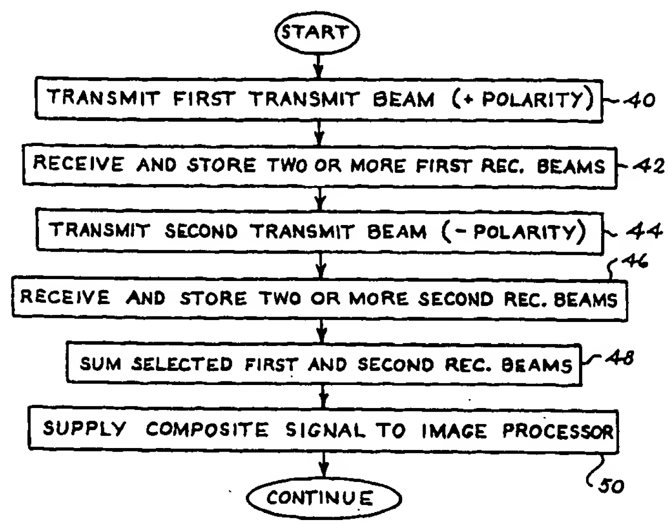

(57) Abstract

A medical diagnostic ultrasound imaging system (10) acquires receive beams from spatially distinct transmit beams (40). The receive beams alternate in type between at least first, and second types (42, 46) across the region being imaged. The first, and second types of receive beams differ in at least one scan parameter other than transmit, receive line geometry, and can for example differ in transmit phase, transmit or receive aperture, system frequency or transmit focus. Predetection receive beams associated with spatially distinct ones of the transmit beams (including at least one beam of the first type, and at least one beam of the second type) are then preferably combined (48) in a coherent manner. In this way two-pulse phase inversion techniques, synthetic aperture techniques, synthetic frequency techniques, and synthetic focus techniques can be used while substantially reducing the frame rate penalty normally associated with such techniques.

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DIAGNOSTIC ULTRASOUND IMAGING METHOD AND SYSTEM WITH IMPROVED FRAME RATE

RELATED APPLICATIONS

This application is a continuation-in-part of co-pending U.S. Patent Application 08/993,395, filed December 18, 1997, and co-pending U.S. Patent Application Serial No. 08/993,533, filed December 18, 1997. Both of these related U.S. Patent Applications are hereby incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

This invention relates to medical diagnostic ultrasonic imaging methods and systems, and in particular to improvements to such systems that allow an increased frame rate.

In various medical diagnostic ultrasonic imaging applications, multiple transmit beams are fired along the same ultrasound line. Examples of such applications include two-pulse techniques that use phase inversion subtraction to enhance harmonic image components, synthetic aperture techniques, synthetic spectrum techniques, and sequential focus techniques. The requirement for multiple transmit pulse firings on each ultrasound line results in a substantial reduction in frame rate.

For example, Chapman U.S. Patent 5,632,277 discloses an ultrasound imaging system that employs phase inversion subtraction to enhance the image. In the disclosed system, two transmit ultrasonic pulses which differ in phase by 180° are focused in the same beam direction. The echo signals associated with these pulses are stored and then summed. Linear echoes destructively interfere in this summation due to the 180° phase difference between the two transmitted ultrasonic pulses. Non-linear echoes do not destructively interfere to the same extent, because the phases associated with non-linear echoes no longer differ by 180°. In this way, the amplitude of

the non-linear echoes can be increased relative to the amplitude of the linear echoes in the summed signal.

The system disclosed in the Chapman patent suffers from the disadvantage that two ultrasonic pulses must be directed along each beam direction, and this requirement reduces the frame rate by a factor of two.

Similarly, Cole U.S. Patent 5,617,862 discusses a system that coherently sums receive beams along the same steering direction to achieve a synthetic aperture. The disclosed system also results in a substantial reduction in frame rate.

The reductions in frame rate discussed above are inevitable in the disclosed systems, and in many cases the frame rate may fall to clinically unacceptable levels. Additionally, the multiple firing techniques discussed above reduce frame rate in discrete steps. For example, when two transmit beam firings are required for each transmit beam direction, the frame rate is reduced by a factor of two as compared to conventional single transmit beam operation. It would be advantageous to have a technique whereby a continuous trade off could be made between selected performance factors and the resulting frame rate when employing various multiple-pulse modes of operation.

SUMMARY

By way of introduction, preferred embodiments described below transmit a plurality of spatially distinct ultrasonic transmit beams into a region. A plurality of pre-detection receive beams are received from the region, each receive beam associated with a respective one of the transmit beams. The transmit and receive beams include beams of at least first and second types. The first and second types of beams differ in at least one scan parameter other than transmit and receive line geometry, and can for example differ in phase, aperture, frequency or focus. Pre-detection receive beams associated with spatially distinct ones of the transmit beams (including at least one beam of the first type and at least one beam of the second type) are then preferably combined in a coherent manner.

Preferably, the first and second types of beams alternate on a line-by-line or group-of-lines by group-of-lines basis. It is the coherent combination that synthesizes the desired feature such as two-pulse cancellation, synthetic aperture, synthetic spectrum, or multiple focus. This approach allows a continuous tradeoff between performance and frame rate by adjustment of the scan line density. For example, if the same scan line density is used in both the normal mode and one of the alternating line modes described above, there is no frame rate loss.

The present invention is defined by the following claims, and nothing in this section should be taken as a limitation on those claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of an ultrasonic imaging system that incorporates a presently preferred embodiment of this invention.

Figure 2 is a flow chart of a portion of a method practiced by the system of Figure 1.

Figures 3 and 4 are schematic diagrams illustrating the formation of a composite signal in two alternative embodiments in which a single receive beam is acquired for each transmit beam.

Figures 5 through 8 are waveform diagrams illustrating the operation of the method shown in Figure 3.

Figures 9 and 10 are schematic diagrams of alternative embodiments in which multiple receive beams are acquired for each transmit beam.

Figure 11 is a diagram showing the spacing of a set of transmit beams generated by the system of Figure 1 as compared to the Nyquist spacing.

Figures 12 and 13 are schematic diagrams of the methods of Figures 3 and 9, respectively.

Figure 14 is a schematic diagram showing transmit apertures utilized in an alternating line aperture embodiment of this invention.

Figures 15-19 are schematic diagrams showing receive apertures used in various alternating line aperture embodiments of this invention.

Figure 20 is a flow chart showing an alternating line focus embodiment of this invention.

Figure 21 is a flow chart showing an alternating line frequency embodiment of this invention.

Figure 22 is a graph showing frequency characteristics of the embodiment of Figure 21.

Figure 23 is a flow chart of an additional embodiment of this invention.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

Alternating Line Phase Embodiments

Referring now to the drawings, Figure 1 shows a schematic view of an ultrasonic imaging system 10 that incorporates a presently preferred embodiment of this invention that provides alternating line phase. The system 10 includes a transmit beamformer 12 that is coupled to a phased transducer array 14 by a multiplexer 16. The multiplexer 16 also couples the transducer array 14 to a receive beamformer 18.

The transmit beamformer 12 in part operates as a conventional transmit beamformer to generate a set of transmit signals for the individual transducers included in the transducer array 14. For example, the transmit beamformer 12 can include a waveform generator 20 that applies a suitably shaped ultrasonic pulse to a focus delay 22. The focus delay 22 provides conventional steering delays by any suitable combination of delays, phase shifts and phase rotations. The focus delays are selected to cause ultrasonic signals from the transducer array 14 to constructively interfere at a selected transmit focus along a selected transmit beam direction. In Figure 1, an exemplary transmit beam T1 is shown.

The transmit beamformer 12 additionally includes a phase inverter 24 that is controlled by a controller 26. In this example, the phase inverter 24 is active only for every other transmit beam. Thus, transmit beams T1, T3,... are transmitted with positive polarity, and transmit beams T2, T4, T6,... are transmitted with inverted or negative polarity.

The receive beamformer 18 can operate in a single beam mode, in which a single receive beam is acquired for each transmit beam, or in a multiple receive beam mode, in which multiple receive beams are acquired in association with each transmit beam. Typically, in the single receive beam mode each receive beam is spatially aligned with the associated transmit beam, while in the multiple receive beam mode each of the receive beams is spatially offset from the respective transmit beam. In Figure 1, two receive beams R1a and R1b are shown in association with the transmit beam T1. As shown in Figure 1, the transmit beams including the transmit beam T1 are directed into a region R of the subject, and the receive beams R1a, R1b are associated with echoes from the region R.

The receive beamformer 18 applies appropriate delays and phase rotations to coherently sum receive signals from the transducer array 14 to create the desired receive beams along desired directions. These receive beams are applied to a line buffer 28 that stores the receive beams for further processing. In this embodiment, the line buffer 28 stores the receive beams coherently. That is, sufficient timing or phase information is preserved, or sufficient phase corrections were made to allow the interference effects discussed below to be obtained consistently.

Selected receive beams associated with multiple, spatially distinct transmit beams are applied to a summer 30 for summation to form a composite signal C that is applied to an image processor 32. The image processor 32 forms a conventional image such as a B mode image and presents this image on a display 34.

Figure 2 provides a flowchart of a portion of a method practiced by the system of Figure 1. The system transmits a first transmit beam of positive polarity in a first direction in step 40, and receives and stores one or more first receive beams associated with this first transmit beam in step 42. Then the transmit beamformer transmits a second transmit beam of negative polarity in a second direction in step 44. The second transmit beam is usually adjacent to the first transmit beam. One or more second receive beams associated with the second transmit beam are received and stored in step 46, and

selected ones of the first and second receive beams are summed in step 48 to generate a composite signal, which is supplied to the image processor in step 50.

Figure 3 illustrates the method of Figure 2 diagrammatically. In Figure 3 the X direction proceeds from left to right, and transmit and receive beams of differing azimuthal positions are plotted at differing X coordinates. Reference numerals 40-50 have been used in Figure 3 to designate portions of Figure 3 that correspond to the correspondingly numbered steps of Figure 2. Note that the first and second receive beams R1, R2 that are summed in step 48 are associated with spatially distinct transmit beams T1 (positive polarity) and T2 (negative polarity), respectively.

Figure 4 shows another embodiment of the method of this invention which includes steps 40-46 as described above. In this embodiment, a third transmit beam T3 (positive polarity) is transmitted along a third spatially distinct direction in step 52, and a corresponding receive beam R3 is acquired in step 54. Thus, the receive beams R1, R2, R3 are all aligned with the corresponding transmit beams T1, T2, T3 and are all spatially distinct. These three receive beams R1, R2, R3 are summed in step 56 using summing values [1, 2, 1] as shown in Figure 4 to generate a composite signal C1 that is applied to the image processor in step 58.

Figures 5-8 diagrammatically illustrate the benefits obtained with the methods of Figures 2-4. Figure 5 shows the ultrasonic waveform associated with the positive polarity transmit beams T1, T3 in solid lines and the inverted or negative polarity ultrasonic waveform associated with transmit pulse T2 in dotted lines. As shown in Figure 5, the inverted polarity pulse differs from the positive polarity pulse by phase inversion or a phase shift of 180°. The ultrasonic pulse shown in Figure 5 is an amplitude modulated sinusoid, and the sinusoid has a fundamental wavelength λ_F. Thus, the pulses shown in Figure 5 represent the fundamental components 80, 82 of the transmit beams T1 and T2, respectively.

Figure 5 can also be taken as a representation of the fundamental components 84, 86 of the receive beams R1, R2, respectively, assuming a

different amplitude scale. The fundamental components 84, 86 of the receive beams are created by linear echoes of the fundamental components 80, 82 of the ultrasonic transmit beams, and the fundamental component 84 of the receive beam R1 is 180° out of phase with respect to the fundamental component 86 of the receive beam R2. Figure 6 schematically shows the summation of the fundamental components 84, 86 of the receive beams R1, R2 . Because the fundamental components 84, 86 are substantially equal in amplitude, and because they differ in phase by 180°, the fundamental components 84, 86 of the receive beams R1, R2 destructively interfere to a substantial extent.

The situation is quite different with respect to the harmonic components of the receive beams R1, R2, as shown in Figure 7. Because the harmonic components 88, 90 of the receive beams R1, R2 are created by non-linear effects, they are not characterized by a phase shift of 180°. In this case, the harmonic components 88, 90 are second harmonic components having a wavelength λ_H equal to one-half of λ_F. In this case, the harmonic receive components 88, 90 have substantially the same phase, and when summed they constructively interfere as shown in Figure 8.

In general, the fundamental components of the receive beams will not destructively interfere completely. Nevertheless, it is important that the fundamental components of the receive beams destructively interfere to a greater extent than the harmonic components of the receive beams, such that the harmonic components of the receive beams are emphasized in the composite signals.

Figures 9 and 10 relate to multiple receive beam embodiments of this invention. In the method flowcharted in Figure 9, a first transmit beam T1 (of positive polarity) is transmitted along a first azimuthal direction in step 60, and two associated receive beams R1a, R1b are acquired in step 62. Note that the receive beams R1a, R1b are offset spatially on respective sides of the transmit beam T1. In step 64, a second transmit beam T2 (of negative polarity) is transmitted along a second transmit direction, spatially distinct from the first transmit direction of the transmit beam T1. Two corresponding

receive beams R2a, R2b are acquired in step 66, and two spatially aligned receive beams R1b, R2a are added together in step 68. Note that the summed receive beams R1b, R2a are spatially aligned along the azimuthal direction, but that they are associated with spatially distinct transmit beams T1, T2, respectively. The summing step 68 generates a composite signal C1 that is applied to the image processor in step 70. The method of Figure 9 is anticipated to provide particularly good rejection of the fundamental component in the composite signal, due to the fact that the summed receive beams R1b and R2a are spatially aligned.

Figure 10 shows a modified form of the method of Figure 9, in which steps 60-66 are performed as described previously. In this case, the summing step 72 sums a total of four receive beams R1a, R1b, R2a, R2b to produce the composite signal C1' that is applied to the image processor in step 74.

In the methods shown in Figures 3, 4, 9 and 10, only a single composite signal is created. In practice, the illustrated methods are repeated as further transmit beams are fired and further receive beams are acquired.

Figure 12 shows the manner in which the method of Figure 3 can be used with multiple transmit beams that traverse the region of interest. In Figure 12, four transmit beams T1-T4 of alternating polarity are used to acquire associated receive beams R1-R4 that are summed as shown to produce composite signals C1-C3. Thus, three composite signals Cl-C3 are acquired using only four transmit events. Similarly, Figure 13 shows the manner in which the method of Figure 9 can be used with transmit beams that traverse the region of interest. In these examples, the advantage of fundamental component rejection is obtained without any substantial penalty in frame rate, since the summed receive signals are associated with spatially distinct transmit beams.

In multiple receive beam embodiments such as those discussed above in conjunction with Figures 9 and 13, the receive beams associated with a single transmit beam may be combined to produce an intermediate combined beam aligned with the respective transmit beam. This intermediate combined

beam does not provide cancellation of fundamental or harmonic components, but it may be useful in various frequency compounding techniques.

Figure 11 schematically shows an array of transmit beams T1-T7 that can be used in the methods described above. In Figure 11, the focal range R_F is illustrated, and the separation between adjacent transmit beams is indicated by the symbol S_B. In Figure 11 the Nyquist spacing (i.e. the beam spacing required for Nyquist sampling) is shown by the symbol S_N. In this embodiment, there is a trade-off between azimuthal spacing of the transmit beams and selective enhancement of the harmonic component in the summing step described above. In particular, if the beam spacing S_B is equal to the Nyquist spacing S_N, an associated azimuthal resolution and level of fundamental component suppression will be obtained. If the transmit beams are positioned more closely together such that the ratio S_B/S_N is less than one, the level of fundamental suppression will be improved in the composite signals at the expense of increased time to acquire a frame of image data. Depending upon the degree of improvement desired in the level of fundamental suppression, the ratio S_B/S_N can be made greater or less than one-half.

In another mode of operation, the ratio S_B/S_N can be made greater than one such that the azimuthal dimension is sampled with a spacing greater than the Nyquist spacing S_N. In this case, the time required to acquire a frame is reduced, but the level of suppression of the fundamental component in the composite signal is reduced. Relationships between the beam spacing S_B and the Nyquist spacing S_N described above can be applied either at the focal range R_F or ranges spaced from the focal range R_F.

For a given transmit line density there is substantially no adverse impact on frame rate due to the use of the fundamental suppression method described above. The fundamental components of the receive beams in general will not be perfectly cancelled due to the fact that the associated transmit beams are spatially distinct, and therefore the phase difference between the fundamental components of the summed receive beams will often be substantially different than 180° such as 180° ± 30° or 180° ± 45°.

However, the more closely the transmit beams are spaced (the more over sampled they are) the better the fundamental cancellation in the composite signal. Thus, the method described above allows a trade-off between frame rate and degree of fundamental rejection in the composite signal. The positive and negative polarity ultrasound lines can approach each other by increasing line density and thereby increasing the rejection of the fundamental component in the composite signal. As a greater degree of oversampling is used, degradation of lateral resolution associated with the summing step is also reduced.

The alternating line phase embodiments described above alternate the polarity of the phase of the transmit beam across scan lines. Coherent combination of the pre-detection receive beams cancels fundamental signals and enhances second harmonic signals, thereby allowing an increase in axial resolution. This technique offers a tradeoff between additional rejection of the fundamental component and frame rate as a function of the selected line density. When operated at Nyquist line spacing, the alternating line phase technique described above can provide additional rejection at up to two times the frame rate of conventional two-pulse techniques.

The alternating line phase techniques can be used (1) to create combined beams that cancel fundamental components and enhance even harmonic components, as described above (by adding the respective receive beams), or (2) to create combined beams that cancel even harmonic components and enhance fundamental components (by subtracting the respective receive beams). If desired, two different combined beams may be generated from a single set of receive beams, one combined beam emphasizing even harmonic components and the other combined beam emphasizing odd harmonic components. Such combined beams can be compounded to reduce speckle effects.

The combined signals described above with enhanced second harmonic components and cancelled or suppressed fundamental components may be used in any of the aberration correction techniques described in U.S.

Patent Application Serial No. 09/061,082 filed April 15, 1998, assigned to the assignee of this invention and hereby incorporated by reference.

As described above, receive signals Y1, Y2 associated with differently-phased transmit beams T1, T2 may be combined by addition (to emphasize the even harmonic components) or by subtraction (to emphasize the fundamental components). Other combinations of Y1 and Y2 are possible, as described for example in Bradley U.S. Patent Application Serial No. 60/095,768, filed August 7, 1998, assigned to the assignee of this invention and hereby incorporated by reference in its entirety. As described in this patent application, the combined signal Zn can take the form

$$Zn = |Y1|^n - |y2|^n$$

where n is a small positive integer. Z_1 corresponds to the first harmonic component; Z_2 corresponds to a compounded combination of the fundamental and first harmonic components. As used herein, the term "combining" is intended broadly to encompass both linear and nonlinear combinations, including the examples set out above as well as other useful combinations of receive signals or beams.

Simply by way of example, the alternating line phase techniques described above can be implemented using a Sequoia™ ultrasonic imaging system available from Acuson Corporation, Mountainview, California, using an Acuson 8L5 transducer. By way of example, the Sequoia™ imaging system can be programmed with the following scan parameters.

transmit f number	-	1.85
transmit apodization	-	half circle
receive f number	-	1.00
receive apodization	-	uniform
transmit center frequency	-	3.5 MHz
receive center frequency	-	7.0 MHz
transmit focus	-	25 mm
receive focus	-	10-25 mm

Or course, all of these parameters can readily be modified as desired, depending on the application.

Alternating Line Aperture Embodiments

In the alternating line aperture embodiments of this invention, the transmit aperture, the receive aperture, or both can be alternated across scan lines. Coherent combination of at least two of the pre-detection receive beams forms a synthetic aperture sum which may increase lateral resolution. In alternative embodiments, the alternate apertures may be left/right, inside/outside, even/odd elements of the transducer, or other variations. For example, transmit beams T1-T4 and receive beams R1-R4 can be created in the geometry shown in Figure 12 discussed above. Adjacent receive beams R1-R2, R2-R3, R3-R4 can be combined to produce composite beams C1, C2 and C3. The system 10 of Figure 1 can be used to implement these alternating line embodiments. For these embodiments the transmit beams T1-T4 can be all of the same polarity, rather than of alternating polarity as described above in conjunction with Figure 12.

As shown in Figure 14, the transmit beams can be provided with a transmit aperture 100 that is centered on the origin 102 of the respective transmit beam. As the origins 102 shift laterally for successive transmit beams, the transmit apertures 100 are shifted in a similar manner.

In this embodiment the receive beams can be considered to be of two types which alternate across the region being imaged. These two types differ in receive aperture. For example, as shown in Figure 15, receive beams of the first type (R1, R3, ...) are acquired with a receive aperture 104 at the left side of the transducer, and receive beams of the second type (R2, R4, ...) are acquired with a receive aperture 106 at the right side of the transducer. If desired, the left and right receive apertures 104, 106 may translate across the face of the transducer to follow the origin of the respective receive beams, as shown in Figure 16. Figure 16 shows one of the receive apertures wrapping from right to left in receive line R2, though such wrapping is not required.

Figure 17 and 18 relate to alternative embodiments in which the receive aperture is divided into an inside portion 108 and two outside portions

110. The receive beams of the first type are acquired using the inside receive aperture 108, and receive beams of the second type are acquired using the outside receive aperture 110. As shown in Figure 18, the inside and outside receive apertures 108, 110 can be moved across the face of the transducer so as to remain centered on the origin of the respective receive lines, with or without wrapping.

Many other apertures may be used for the two or more receive apertures associated with respective receive beams. For example, as shown in Figure 24, even transducer elements may be used for a first receive aperture 108 for receive beams of the first type, and odd transducer elements may be used for a second receive aperture 110 for receive beams of the second type.

With this arrangement the receive beams that are combined to create the composite beams are of differing types, and the combined beams are therefore characterized by a synthetic aperture that includes signal information associated with multiple apertures (e.g., left/right, inside/outside, or even/odd) in the various embodiments discussed above.

By way of example, the Acuson Sequoia™ ultrasonic imaging system can be used with an Acuson 8L5 transducer to implement the alternating line aperture embodiments described above. By way of example, the following scan parameters can be used:

transmit f number	-	2.0
transmit apodization	-	half circle
receive f number	-	1.0
receive apodization	-	uniform
transmit focus	-	25 mm
receive focus	-	10-25 mm

As before, all of these parameters can readily be modified as desired, depending on the application.

Though not shown in the drawings, a multiple receive beam acquisition method similar to that of Figure 13 can also be modified to provide the alternating line aperture features discussed above.

If desired, the transmit aperture may also be varied between the first and second types of receive beams, and in some cases more than two types of beams will be appropriate. For example, three different receive apertures can be provided, and three receive beams (one from each aperture type) can be coherently summed to create a synthetic aperture combined beam.

Alternating Line Focus Embodiments

In these embodiments the location of the transmit focus is alternated across scan lines. Coherent combination of the associated receive beams forms a composite beam with improved transmit depth of field at higher frame rates as compared to standard sequential focusing methods, in which multiple segmented portions of an image are acquired with separate respective transmit beams are stitched together.

By way of example, Figure 20 shows a schematic view of a beam acquisition method similar to that of Figure 12. In the schematic view of Figure 20, the transmit focus 112, 114 is indicated by a dark triangle. As shown in Figure 20, transmit beams of the first type (T1, T3, ...) are characterized by a relatively distant transmit focus 112, and transmit beams of the second type (T2, T4, ...) are characterized by a relatively shallow transmit focus 114. Receive beams R1-R2, R2-R3, R3-R4, ... are combined, and in each case the combined receive beams are associated with transmit beams of the first type as well as transmit beams of the second type. Thus, the resulting composite beams C1, C2, C3 ... have an improved transmit depth of field.

Though not shown in the drawings, a multiple receive beam acquisition method similar to that of Figure 13 can also readily be modified to provide the alternating line focus features discussed above.

Alternating Line Frequency Embodiments

At any given system operating frequency (system sampling rate, filter bandwidth, and so forth), there exists only a limited amount of pulse bandwidth, which can be less than that available from the transducer.

In the alternating line frequency embodiments of this invention, the receive beamformer frequency of operation (system sampling rates, filter bandwidths, and so forth) are alternated from scan line to scan line. Coherent combination of these lines forms a composite line with increased bandwidth at higher frame rates as compared with conventional multipulse methods.

Figure 21 shows an embodiment of this invention in which the receive lines of the first type (R1, R3, ...) are acquired with a frequency of operation f1, while receive beams of a second type (R2, R4, ...) are acquired with a frequency of operation f2. Adjacent receive beams of the first and second type are coherently combined to produce composite beams C1, C2, C3, ... having an increased bandwidth, as shown in Figure 22. In Figure 22, the bandwidth of the receive beams of the first and second types are shown at 115, 116, respectively, and the bandwidth of the composite beams is shown at 117. This advantage of a large bandwidth for the composite beams is obtained at a high frame rate.

Though not shown in the drawings, the alternating line frequency embodiments can also implement a multiple receive beam acquisition scheme similar to that of Figure 13, in which multiple receive beams are acquired in response to each respective transmit beam.

Additional Embodiments

Other embodiments of this invention transmit a set of ultrasonic transmit beams into a region, including in some cases spatially aligned transmit beams.

Fundamental components of selected transmit beams are characterized by a phase difference of 180°. Ultrasonic receive beams are acquired from the region, and multiple receive beams are associated with each respective one of the transmit beams. At least two receive beams are

summed to form a composite signal, and the phase difference in the fundamental transmit components is effective to cause fundamental components of the receive beams to destructively interfere to a greater extent than harmonic components of the receive beams. In some embodiments, three or more receive beams are summed to form the composite signal.

For example, the system of Figure 1 can be used to practice the methods of Figures 9 and 10 with spatially aligned transmit beams.

Figure 23 shows a flowchart of another embodiment of the method of this invention. In the method of Figure 23, a first transmit beam T1 (positive polarity) is transmitted along a first azimuthal direction in step 140, and in step 142 two spatially distinct receive beams R1a, R1b are received. As shown in Figure 23, receive beams R1a and R1b are offset on respective sides of the azimuthal direction of the transmit beam T1. In step 144, a second transmit beam T2 (negative polarity) is transmitted along the same azimuthal direction as transmit beam T1, and in step 146 two receive beams R2a, R2b are received. In this embodiment, receive beams R1a, R2a, are spatially aligned and receive beams R1b, R2b are spatially aligned. In step 148, spatially aligned receive beams R1a, R2a are summed and spatially aligned receive beams R1b, R2b are separately summed to form composite signals C1, C2 respectively. In step 150 the composite signals C1, C2 are applied to the image processor.

In the method of Figure 23 two transmit beams are required to generate two composite signals, and therefore the composite signals C1, C2 are acquired with no degradation of temporal resolution or frame rate as compared to conventional single pulse imaging techniques.

<u>Conclusion</u>

Of course, many changes and modifications can be made to the preferred embodiments described above. For example, combinations of the various embodiments described above are possible. In one alternative embodiment, both transmit phase and receive aperture are alternated among

beams, using either sequential or simultaneous alternation techniques. For example, in one sequential alternation embodiment left and right receive apertures are alternated with a positive transmit polarity phase over two scan lines, and then left and right receive apertures are alternated with negative transmit polarity over the next two scan lines, and all four scan lines are coherently summed to create the composite beam. In one simultaneous alteration technique a positive transmit polarity pulse/left (or inside or even element) receive aperture configuration is alternated with a negative transmit polarity pulse/right (or outside or odd element) receive aperture, and two scan lines are coherently summed to create the composite beam. Simultaneous alteration techniques are preferred for two or more alternating parameters if there is little or no interaction between or among the parameters. In general, the line density controls the resulting performance level and frame rate. In cases where synthetic line features are available with sufficient bandwidths, each of the proposed modes and combinations described above can be programmed to have the same frame rate advantage; however, performance can be improved since common receive lines can be coincident yet multiple coincident transmit lines are avoided to eliminate any unnecessary decrease in the frame rate. This can offer advantages when tissue motion is an issue, as in cardiology applications.

In the embodiments described above, selected pre-detection receive beams are coherently combined. Coherent combination is discussed extensively in the above-identified U.S. Patent 5,667,373, assigned to the assignee of this invention, and the entirety of the disclosure of this patent is hereby incorporated by reference for its teaching regarding alternative forms of coherent combination.

The methods described above can be used both in situations where a non-linear contrast agent is introduced into the region of interest as well as in situations in which the region of interest is maintained free of added non-linear contrast agent. For example, the methods described above can be used during a medical diagnostic examination session in which the subject is maintained free of added non-linear contrast agent during the entire session.

In this case, the harmonic components described above are generated by natural processes associated with the propagation of ultrasound through body tissues.

The systems and methods described above can be implemented using a wide variety of hardware. For example, the transmit beamformer 12 and the receive beamformer 18 can be made to operate using any suitable architecture, including both analog and digital architectures. The beamformers 12, 18 can also be of the simultaneous multi-beam transmit-multi beam receive, particularly where simultaneous transmit beams are widely spaced.

The transducer array 14 can be a one-dimensional, 1.5 dimensional or 2 dimensional array, flat or curved, and of either constant or varying thickness. The transmit beams can be formed of transmit waveforms of the widest variety of shapes including unipolar and bipolar pulses, with or without smoothly rising and falling envelopes. Sinusoidal, square wave or multi-level square wave techniques can be used. The waveform generator 20 and the focus delay 22 can vary widely in complexity and sophistication. The phase inverter 24 can operate in an analog or digital fashion, and it can be implemented by delays, phase rotations or phase inversions. The controller 26 can be included as part of the transmit beamformer 12; alternately the phase inverter 24 can be implemented separately from the transmit beamformer 12. The controller 26 may control the phase inverter 24 without controlling other elements of the system. The line buffer 28 and the summer 30 can be implemented as analog or digital systems, and the line buffer 28 may correspond to a digital memory for multiple receive beams.

The methods described above can be implemented over a full frame of image data or part of a frame, and they can be used with a wide variety of ultrasonic imaging signals including B mode signals, Doppler signals and the like. Though the examples described above emphasize second harmonic components, this invention is not limited to use with second harmonic signals. As used herein, the term “harmonic” is intended broadly to encompass any

non-linear echo signal, including sub-harmonics, fractional harmonics and integral harmonics of 2 and greater.

As indicated above, various embodiments of this invention will obtain various degrees of cancellation of the fundamental components by destructive interference in the composite signal. Thus, the term "destructive interference" is intended broadly to encompass both partial and complete interference.

The present invention can be used with any suitable scan line geometry, including sector, Vector®, and parallel beam geometries, for example.

As used herein, the term "scan parameter" is intended broadly to encompass transmit and/or receive parameters other than beam steering direction and beam origin.

The term "spatially distinct" is intended broadly to encompass transmit lines that are spatially distinct in azimuth, in elevation, or both.

With respect to the embodiments described above that utilize transmit beams which are entirely spatially distinct from one another, it may be desirable to fire additional transmit beams which are spatially aligned with previously fired transmit beams.

The foregoing detailed description has discussed only a few of the many forms that this invention can take. It is therefore intended that the foregoing detailed description be regarded as illustrative rather than limiting. It is only the following claims, including all equivalents, that are intended to define the scope of this invention.

CLAIMS

1. A medical diagnostic ultrasound imaging method comprising the following steps:

(a) transmitting a plurality of spatially distinct ultrasonic transmit beams into a region;

(b) receiving a plurality of pre-detection receive beams from the region, each receive beam associated with a respective one of the transmit beams; said transmit beams and said associated receive beams comprising at least first and second types of beams which differ in at least one scan parameter other than transmit and receive beam steering direction and beam origin;

(c) coherently combining at least two of the pre-detection receive beams associated with spatially distinct ones of the transmit beams, said combined receive beams associated with at least one beam of the first type and at least one beam of the second type.

2. The method of Claim 1 wherein the at least one scan parameter comprises transmit phase.

3. The method of Claim 2 wherein step (c) comprises the step of

(c1) coherently combining said at least two of the pre-detection receive beams to enhance a harmonic component thereof; and

(c2) coherently combining said at least two of the pre-detection receive beams to enhance a fundamental component thereof.

4. The method of Claim 1 wherein the at least one scan parameter comprises a plurality of scan parameters.

5. The method of Claim 1 wherein the at least one scan parameter comprises aperture.

6. The method of Claim 5 wherein step (b) includes the step of varying receive aperture between a first receive aperture comprising even

transducer elements for the first type of beams and a second receive aperture comprising odd transducer elements for the second type of beams.

7. The method of Claim 1 wherein the at least one scan parameter comprises system frequency.

8. The method of Claim 1 wherein the at least one scan parameter comprises transmit focus.

9. The method of Claim 1, 2 or 8 wherein the transmit beams transmitted in step (a) alternate between the first and second types of beams across the region.

10. The method of Claim 1, 5 or 7 wherein the receive beams received in step (b) alternate between the first and second type of beams across the region.

11. The method of Claim 1 wherein a single respective one of the receive beams is received in step (b) in response to each of the transmit beams.

12. The method of Claim 1 wherein at least two respective ones of the receive beams are received in step (b) in response to each of the transmit beams.

13. The method of Claim 1 wherein the first and second types of beams comprise transmit beams that differ in at least one scan parameter other than transmit beam steering direction and beam origin.

14. The method of Claim 1 wherein the first and second types of beams comprise receive beams that differ in at least one scan parameter other than receive beam steering direction and beam origin.

15. A medical diagnostic ultrasound imaging system comprising:

means for transmitting a plurality of spatially distinct ultrasonic transmit beams into a region;

means for receiving a plurality of pre-detection receive beams from the region, each receive beam associated with a respective one of the transmit beams; said transmit beams and said associated receive beams comprising at least first and second types of beams which differ in at least one scan parameter other than transmit and receive beam steering direction and beam origin;

means for coherently combining at least two of the pre-detection receive beams associated with spatially distinct ones of the transmit beams, said combined receive beams associated with at least one beam of the first type and at least one beam of the second type.

16. The invention of Claim 15 wherein the at least one scan parameter comprises transmit phase.

17. The invention of Claim 15 wherein the at least one scan parameter comprises aperture.

18. The invention of Claim 15 wherein the receiving means comprises means for varying receive aperture between a first receive aperture comprising even transducer elements for the first type of beams and a second receive aperture comprising odd transducer elements for the second type of beams.

19. The invention of Claim 15 wherein the at least one scan parameter comprises system frequency.

20. The invention of Claim 15 wherein the at least one scan parameter comprises transmit focus.

21. The invention of Claim 15, 16 or 20 wherein the transmitting means alternates the transmit beams between the first and second types of beams across the region.

22. The invention of Claim 15, 17 or 19 wherein the receiving means alternates the receive beams between the first and second types of beams across the region.

23. The invention of Claim 15 wherein the receiving means receives a single respective one of the receive beams in response to each of the transmit beams.

24. The invention of Claim 15 wherein the receiving means receives at least two respective ones of the receive beams in response to each of the transmit beams.

25. The invention of Claim 15 wherein the first and second types of beams comprise transmit beams that differ in at least one scan parameter other than transmit beam steering direction and beam origin.

26. The method of Claim 15 wherein the first and second types of beams comprise receive beams that differ in at least one scan parameter other than receive beam steering direction and beam origin.

27. An ultrasonic imaging method comprising the following steps:

(a) transmitting a set of ultrasonic transmit beams into a region, at least some of the transmit beams focused at spatially distinct directions, said transmit beams each comprising a respective fundamental transmit component, the fundamental transmit components associated with selected ones of the transmit beams characterized by a phase difference;

(b) receiving a plurality of ultrasonic receive beams from the region, each receive beam associated with a respective one of the transmit beams, and each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

(c) summing at least two of the receive beams associated with spatially distinct ones of the transmit beams to form a composite signal, said phase difference of step (a) selected to cause the fundamental receive

components to destructively interfere to a greater extent than the harmonic receive components in the summing step.

28. The method of Claim 27 wherein the transmit beams traverse the region.

29. The method of Claim 27 wherein each of the receive beams is spatially aligned with the respective associated transmit beam.

30. The method of Claim 27 wherein at least some of the receive beams are spatially offset from the respective associated transmit beams.

31. The method of Claim 30 wherein step (b) comprises the step of receiving a respective plurality of the receive beams in association with each transmit beam.

32. The method of Claim 27 or 31 wherein the receive beams summed in step (c) are spatially aligned.

33. The method of Claim 27 wherein the receive beams summed in step (c) are spatially distinct.

34. The method of Claim 27 wherein step (b) comprises the step of receiving two of the receive beams in association with each of the transmit beams, and wherein the receive beams summed in step (c) are spatially aligned.

35. The method of Claim 27 wherein the phase difference approaches 180°.

36. The method of Claim 27 further comprising the step of introducing a non-linear contrast agent into the region prior to step (a).

37. The method of Claim 27 wherein steps (a)-(c) are performed during a medical diagnostic examination session, and further comprising the step of maintaining the region free of added non-linear contrast agent during the entire medical diagnostic examination session.

38. The method of Claim 27 wherein step (c) comprises the step of coherently summing said at least two of the receive beams to form the composite signal.

39. The method of Claim 27 wherein the transmit beams are spaced at a selected range to provide Nyquist sampling.

40. The method of Claim 27 wherein the transmit beams are spaced at a selected range by a separation S_B greater than a separation S_N required for Nyquist sampling.

41. The method of Claim 27 wherein the transmit beams are spaced at a selected range by a separation S_B less than a separation S_N required for Nyquist sampling, and wherein S_B/S_N is no less than ½.

42. The method of Claim 27 wherein the transmit beams are spaced at a selected range by a separation S_B less than a separation S_N required for Nyquist sampling, and wherein S_B/S_N is less than ½.

43. The method of Claim 39, 40, 41 or 42 wherein the transmit beams are characterized by a transmit focal range and wherein the selected range is at the transmit focal range.

44. The method of Claim 39, 40, 41 or 42 wherein the transmit beams are characterized by a transmit focal range, and wherein the selected range is spaced from the transmit focal range.

45. The method of Claim 27 wherein step (a) comprises the step of inverting a phase of the fundamental transmit components for alternate ones of the transmit beams such that the phase difference is about equal to 180°.

46. In an ultrasonic imaging system comprising:

a transducer array;

a transmit beamformer coupled to the transducer array and operative to transmit a set of ultrasonic transmit beams into a region, said transmit beams focused at spatially distinct directions, said transmit beams each comprising a respective fundamental transmit component;

a controller coupled to the transmit beamformer and operative to cause the fundamental transmit components associated with selected ones of the transmit beams to differ from one another by a selected phase difference;

a receive beamformer coupled to the transducer array and operative to receive a plurality of receive beams from the region, each receive beam associated with a respective one of the transmit beams, and each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

a summer operative to sum at least two of the receive beams associated with spatially distinct ones of the transmit beams to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the composite signal.

47. The method of Claim 46 wherein the transmit beams traverse the region.

48. The method of Claim 46 wherein each of the receive beams is spatially aligned with the respective associated transmit beam.

49. The method of Claim 46 wherein at least some of the receive beams are spatially offset from the respective associated transmit beams.

50. The method of Claim 46 wherein the receive beamformer is operative to receive a respective plurality of the receive beams in association with each transmit beam.

51. The invention of Claim 46 or 50 wherein the receive beams summed in the summer are spatially aligned.

52. The invention of Claim 46 wherein the receive beams summed in the summer are spatially distinct.

53. The invention of Claim 46 wherein the phase difference approaches 180°.

54. The invention of Claim 46 wherein the summer is operative to coherently sum said at least two of the receive beams to form the composite signal.

55. The method of Claim 46 wherein the transmit beams are spaced at a selected range to provide Nyquist sampling.

56. The method of Claim 46 wherein the transmit beams are spaced at a selected range by a separation S_B greater than a separation S_N required for Nyquist sampling.

57. The method of Claim 46 wherein the transmit beams are spaced at a selected range by a separation S_B less than a separation S_N required for Nyquist sampling, and wherein S_B/S_N is no less than ½.

58. The method of Claim 46 wherein the transmit beams are spaced at a selected range are spaced by a separation S_B less than a separation S_N required for Nyquist sampling, and wherein S_B/S_N is less than ½.

59. The method of Claim 55, 56, 57 or 58 wherein the transmit beams are characterized by a transmit focal range, and wherein the selected range is at the transmit focal range.

60. The method of Claim 55, 56, 57 or 58 wherein the transmit beams are characterized by a transmit focal range, and wherein the selected range is spaced from the transmit focal range.

61. The invention of Claim 46 wherein the transmit beamformer comprises an inverter, responsive to the controller, operative to invert a phase of the fundamental transmit components for alternate ones of the transmit beams such that the phase difference is about equal to 180°.

62. An ultrasonic imaging method comprising the following steps:

(a) transmitting a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component, the fundamental transmit components associated with selected ones of the transmit beams characterized by a phase difference;

(b) receiving a plurality of ultrasonic receive beams from the region, at least two of the receive beams associated with each respective one of the transmit beams, each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

(c) summing at least two of the receive beams to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the summing step.

63. The method of Claim 62 wherein the receive beams summed in step (c) are spatially aligned.

64. The method of Claim 62 wherein at least some of the receive beams summed in step (c) are spatially distinct.

65. The method of Claim 62 or 63 wherein the transmit beams associated with the receive beams summed in step (c) are spatially aligned.

66. The method of Claim 62 or 63 wherein the transmit beams associated with the receive beams summed in step (c) are spatially distinct.

67. An ultrasonic imaging system comprising:

a transducer array;

a transmit beamformer coupled to the transducer array and operative to transmit a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component;

a controller coupled to the transmit beamformer and operative to cause the fundamental transmit components associated with selected ones of the transmit beams to differ from one another by a selected phase difference;

a receive beamformer coupled to the transducer array and operative to receive a plurality of receive beams from the region in response to each respective one of the transmit beams, each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

a summer operative to sum at least two of the receive beams to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the composite signal.

68. The invention of Claim 67 wherein the receive beamformer is operative to receive the receive beams summed by the summer as spatially aligned receive beams.

69. The invention of Claim 67 wherein the receive beamformer is operative to receive at least some of the receive beams summed by the summer as spatially distinct receive beams.

70. The invention of Claim 67 or 68 wherein the transmit beamformer is operative to transmit the transmit beams associated with the receive beams summed by the summer as spatially aligned transmit beams.

71. The invention of Claim 67 or 68 wherein the transmit beamformer is operative to transmit the transmit beams associated with the receive beams summed by the summer as spatially distinct transmit beams.

72. An ultrasonic imaging method comprising the following steps:

(a) transmitting a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component, the fundamental transmit components associated with selected ones of the transmit beams characterized by a phase difference;

(b) receiving a plurality of ultrasonic receive beams from the region, each receive beam associated with a respective one of the transmit beams, and each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

(c) summing at least two spatially distinct ones of the receive beams to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the summing step.

73. The method of Claim 72 wherein three of the receive beams are summed in step (c).

74. The method of Claim 72 wherein four of the receive beams are summed in step (c).

75. An ultrasonic imaging system comprising:

a transducer array;

a transmit beamformer coupled to the transducer array and operative to transmit a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component;

a controller coupled to the transmit beamformer and operative to cause the fundamental transmit components associated with selected ones of the transmit beams to differ from one another by a selected phase difference;

a receive beamformer coupled to the transducer array and operative to receive a plurality of receive beams from the region in response to the transmit beams, each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

a summer operative to sum at least two spatially distinct ones of the receive beams to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the composite signal.

76. The invention of Claim 75 wherein the summer is operative to sum three of the receive beams.

77. The invention of Claim 75 wherein the summer is operative to sum four of the receive beams.

78. An ultrasonic imaging method comprising the following steps:

(a) transmitting a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component, the fundamental transmit components associated with selected ones of the transmit beams characterized by a phase difference;

(b) receiving a plurality of ultrasonic receive beams from the region, each receive beam associated with a respective one of the transmit beams, and each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

(c) summing at least three of the receive beams using at least two different summing weights to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the summing step.

79. An ultrasonic imaging system comprising:

a transducer array;

a transmit beamformer coupled to the transducer array and operative to transmit a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component;

a controller coupled to the transmit beamformer and operative to cause the fundamental transmit components associated with selected ones of the transmit beams to differ from one another by a selected phase difference;

a receive beamformer coupled to the transducer array and operative to receive a plurality of receive beams from the region in response to the transmit beams, each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

a summer operative to sum at least three of the receive beams using at least two different summing weights to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the composite signal.

80. An ultrasonic imaging method comprising the following steps:

(a) transmitting a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component, the fundamental transmit components associated with selected ones of the transmit beams characterized by a phase difference;

(b) receiving a plurality of ultrasonic receive beams from the region, each receive beam associated with a respective one of the transmit beams, and each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

(c) summing an odd number of the receive beams to form a composite signal, said phase difference effective to cause the fundamental

receive components to destructively interfere to a greater extent than the harmonic receive components in the summing step.

81. The method of Claim 80 wherein the odd number is three.

82. An ultrasonic imaging system comprising:

a transducer array;

a transmit beamformer coupled to the transducer array and operative to transmit a set of ultrasonic transmit beams into a region, said transmit beams each comprising a respective fundamental transmit component;

a controller coupled to the transmit beamformer and operative to cause the fundamental transmit components associated with selected ones of the transmit beams to differ from one another by a selected phase difference;

a receive beamformer coupled to the transducer array and operative to receive a plurality of receive beams from the region in response to the transmit beams, each receive beam comprising a respective fundamental receive component and a respective harmonic receive component;

a summer operative to sum an odd number of receive beams to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a greater extent than the harmonic receive components in the composite signal.

83. The invention of Claim 82 wherein the odd number is three.

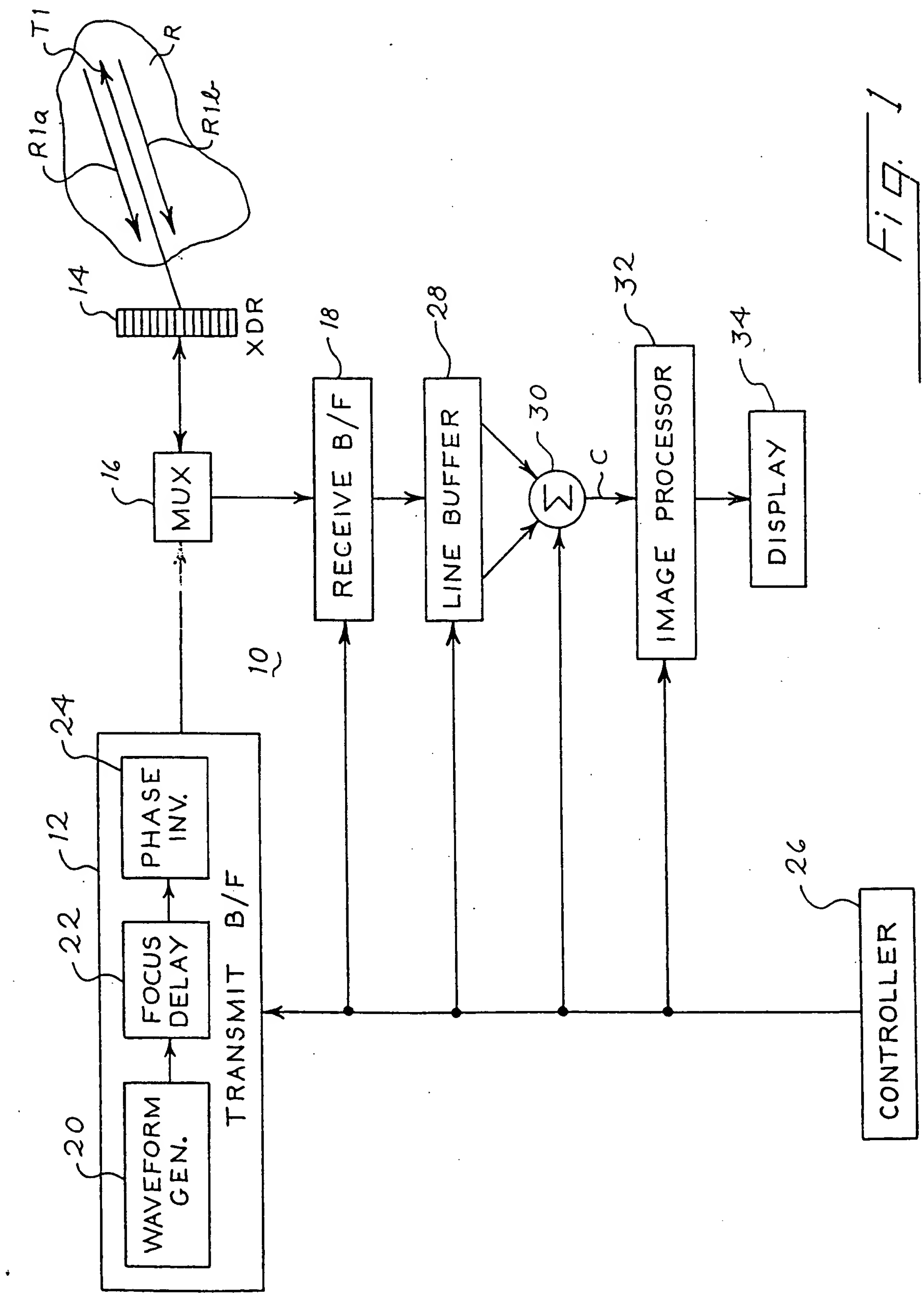

T1
R
R1a
R1b
14
XDR
16
MUX
18
RECEIVE B/F
28
LINE BUFFER
30
C
32
IMAGE PROCESSOR
34
DISPLAY
10
24
PHASE INV.
12
22
FOCUS DELAY
20
WAVEFORM GEN.
TRANSMIT B/F
26
CONTROLLER

Fig. 1

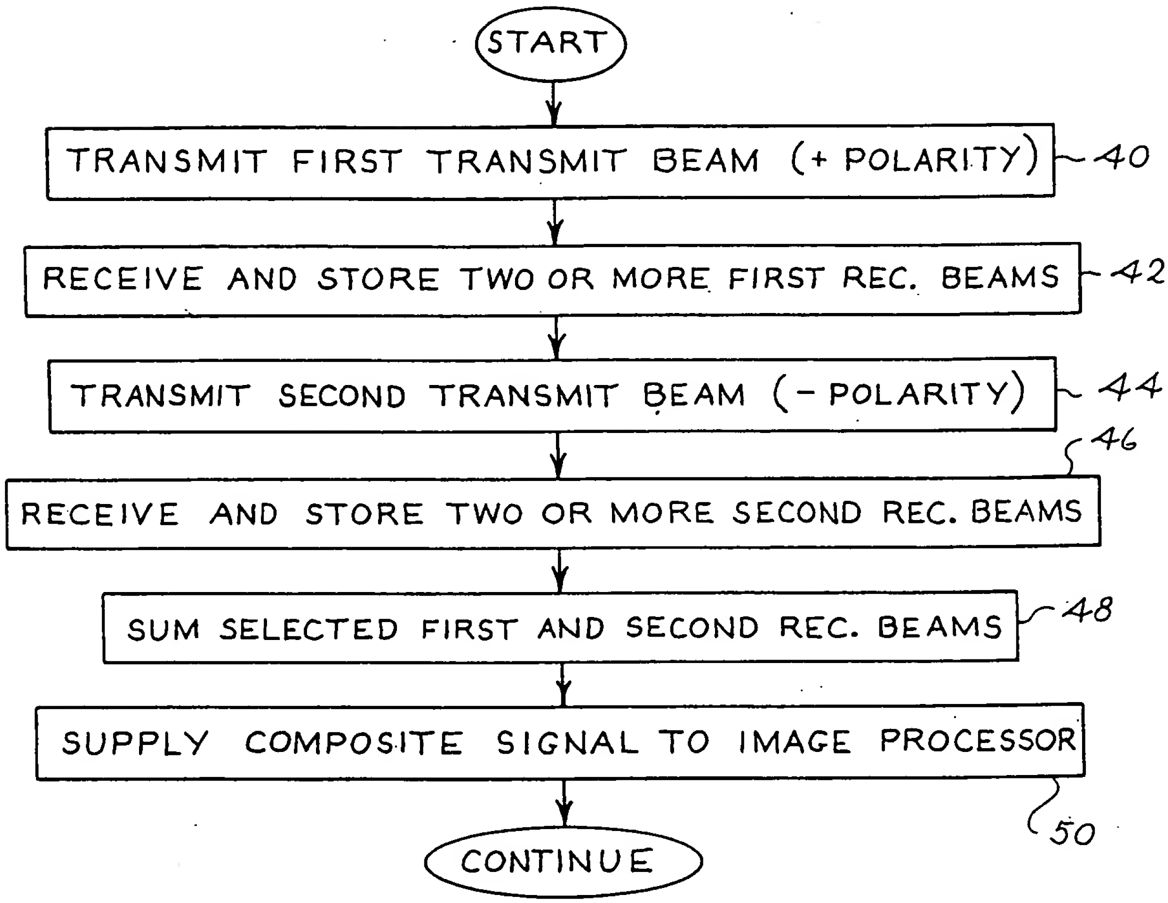

START
TRANSMIT FIRST TRANSMIT BEAM (+ POLARITY)
40
RECEIVE AND STORE TWO OR MORE FIRST REC. BEAMS
42
TRANSMIT SECOND TRANSMIT BEAM (- POLARITY)
44
46
RECEIVE AND STORE TWO OR MORE SECOND REC. BEAMS
SUM SELECTED FIRST AND SECOND REC. BEAMS
48
SUPPLY COMPOSITE SIGNAL TO IMAGE PROCESSOR
50
CONTINUE

Fig. 2

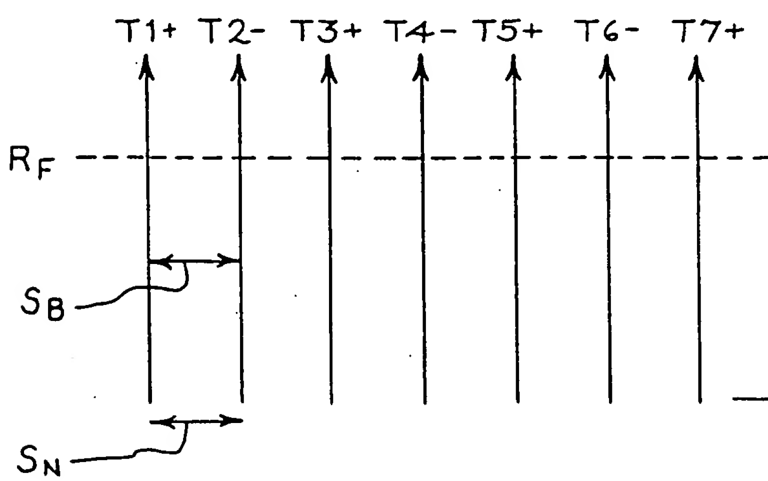

T1+ T2- T3+ T4- T5+ T6- T7+
R_F
S_B
S_N

Fig. 11

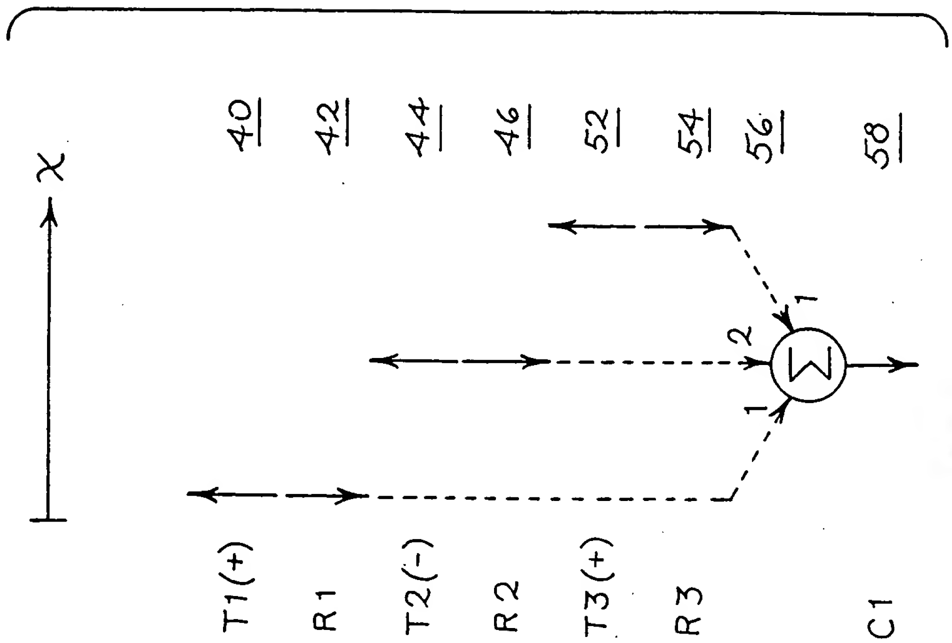

x
T1(+)
R1
T2(-)
R2
T3(+)
R3
C1
40
42
44
46
52
54
56
58
1
2
1

Fig. 4

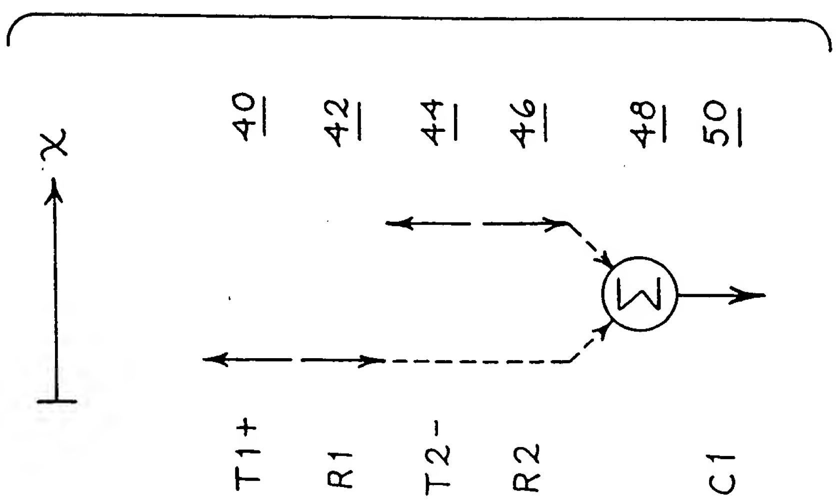

x
T1+
R1
T2-
R2
C1
40
42
44
46
48
50

Fig. 3

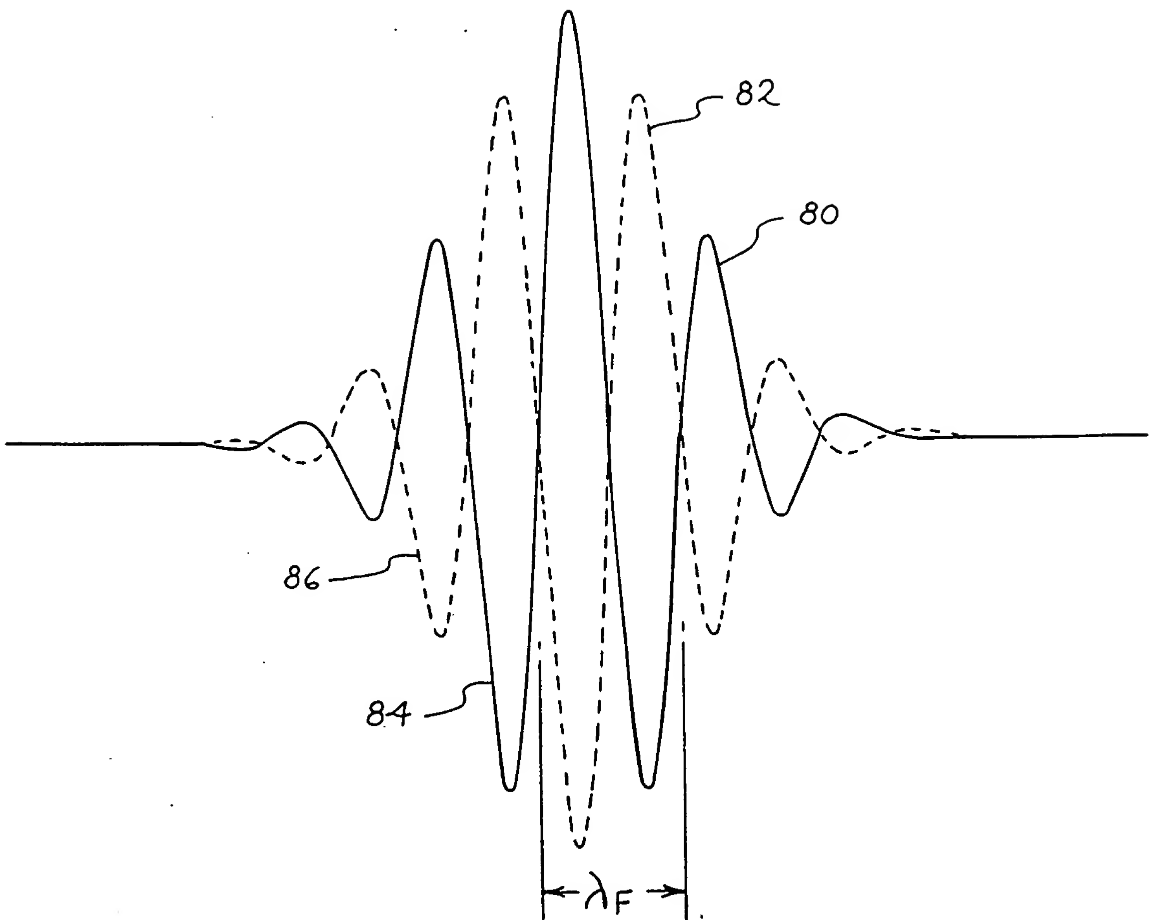


Fig. 5

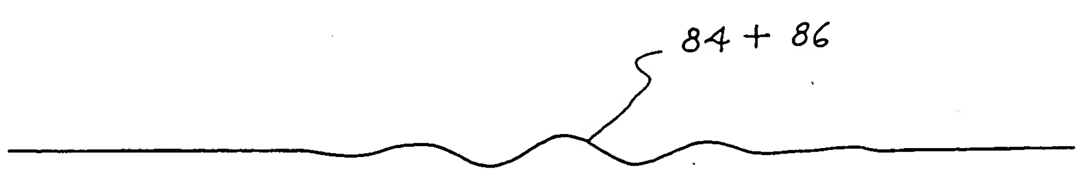


Fig. 6

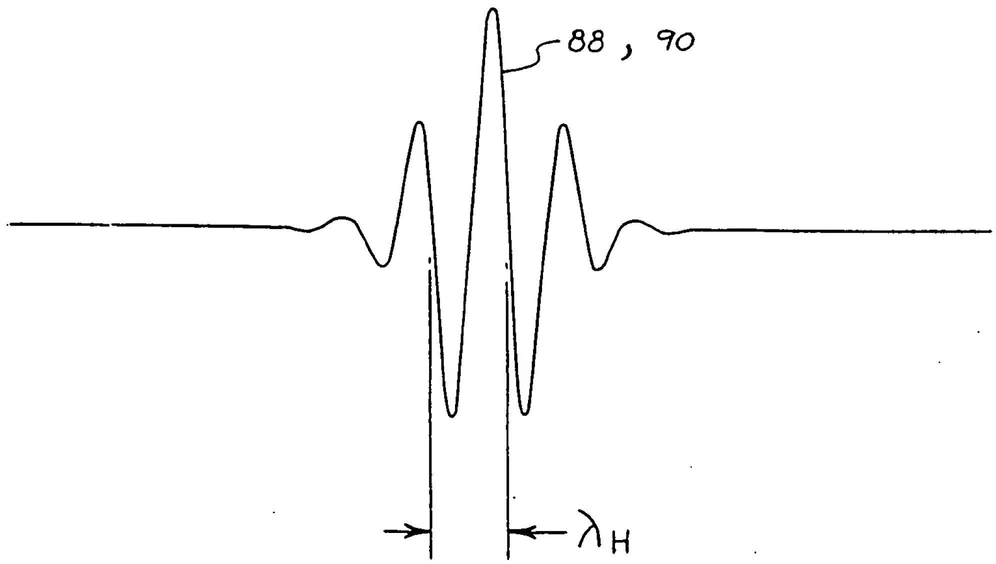


Fig. 7

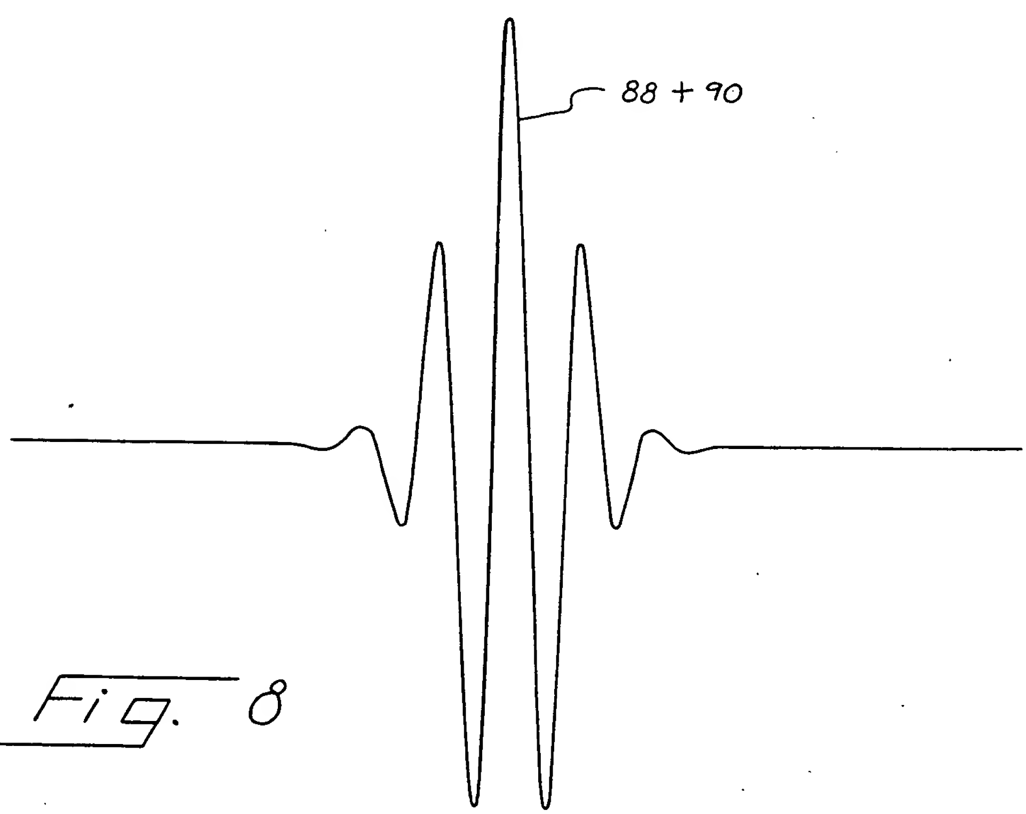


Fig. 8

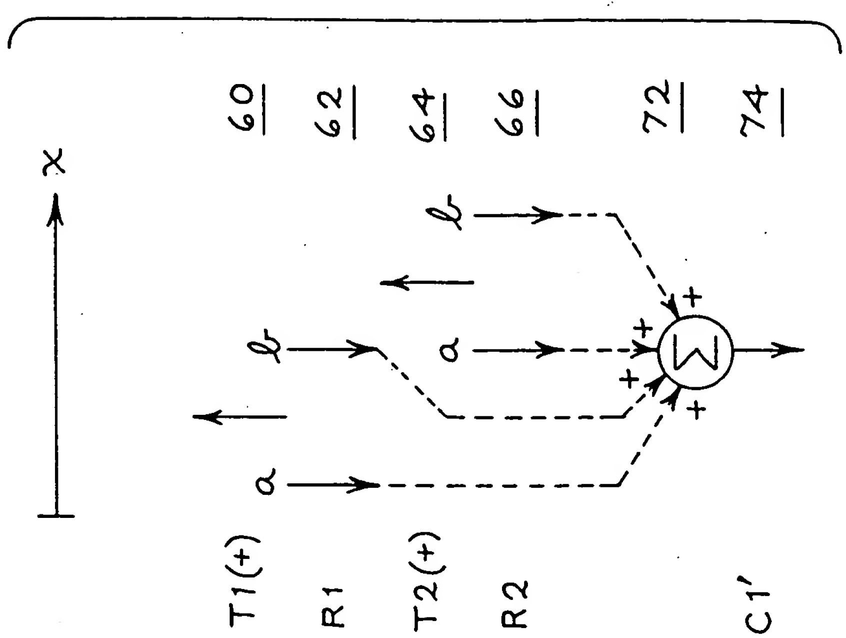


Fig. 10

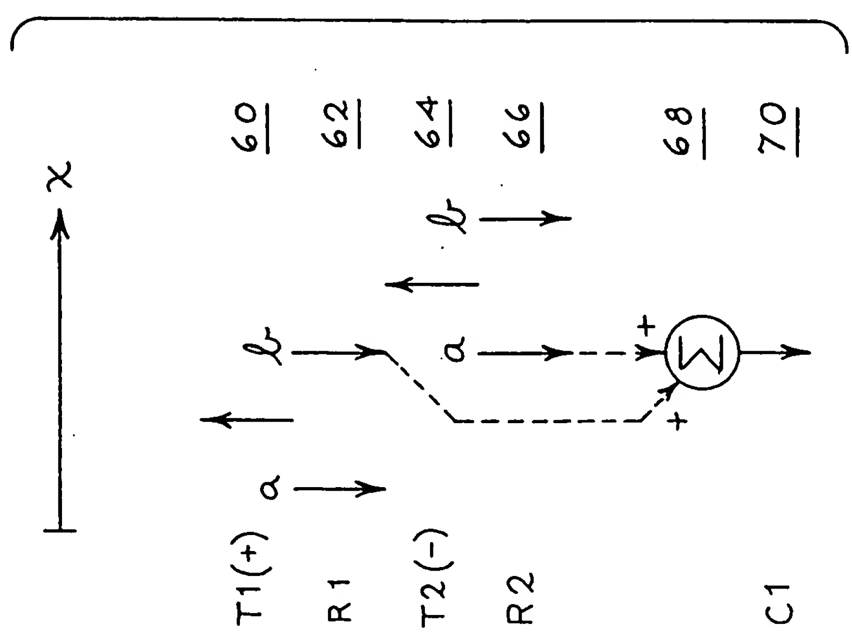


Fig. 9

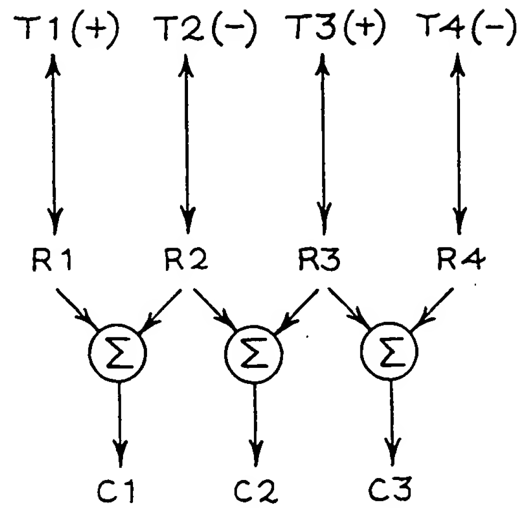

T1(+)
T2(-)
T3(+)
T4(-)
R1
R2
R3
R4
Σ
Σ
Σ
C1
C2
C3

Fig. 12

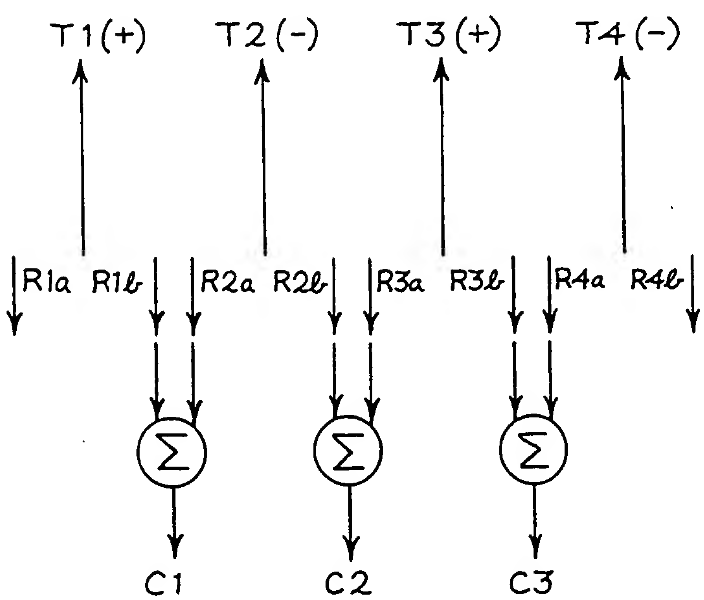

T1(+)
T2(-)
T3(+)
T4(-)
R1a
R1b
R2a
R2b
R3a
R3b
R4a
R4b
Σ
Σ
Σ
C1
C2
C3

Fig. 13

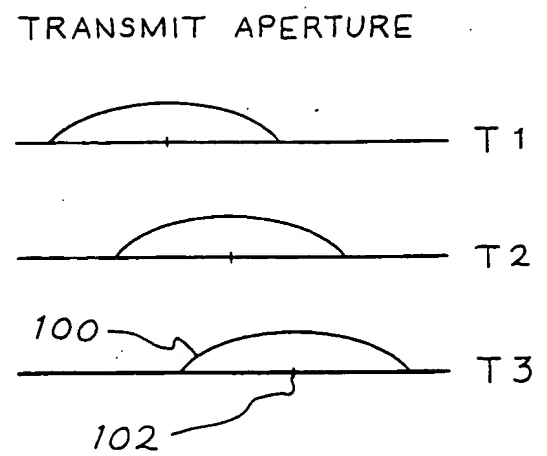


Fig. 14

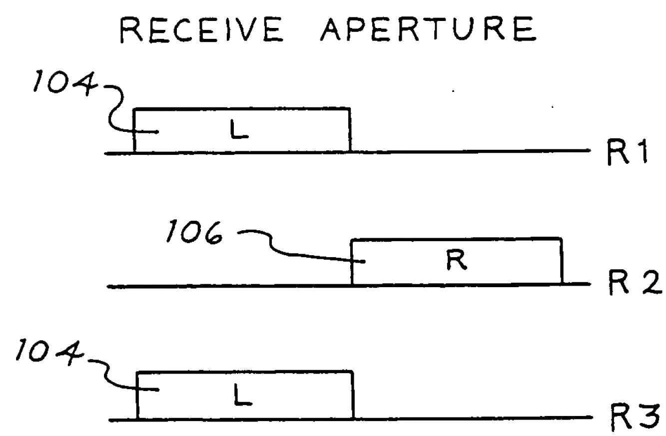


Fig. 15

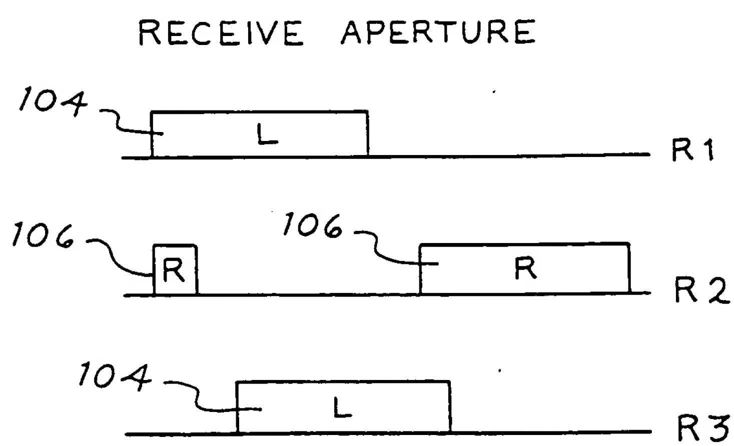


Fig. 16

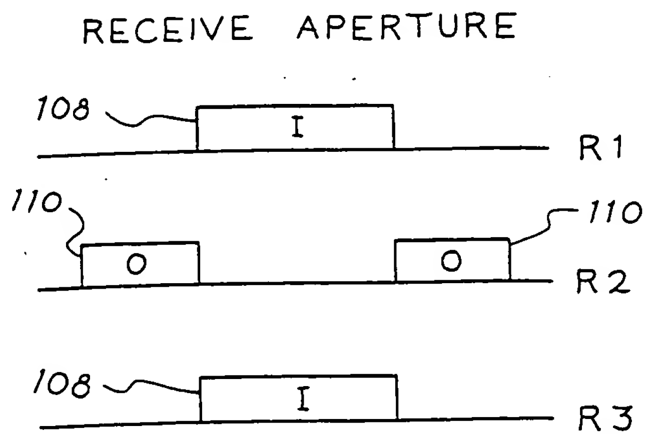


Fig. 17

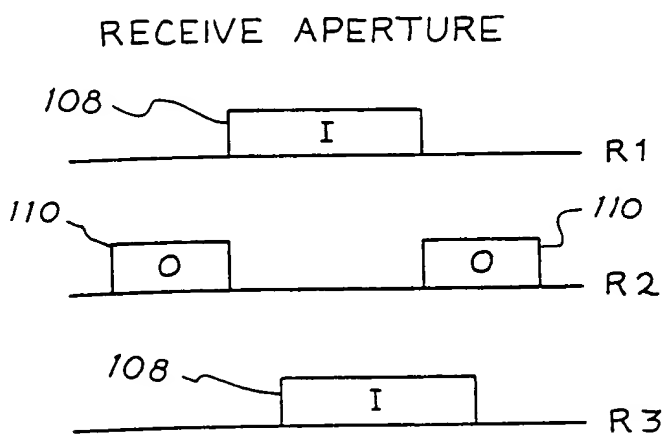


Fig. 18

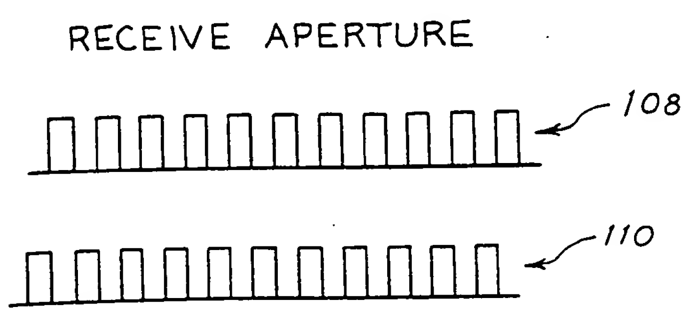


Fig. 19

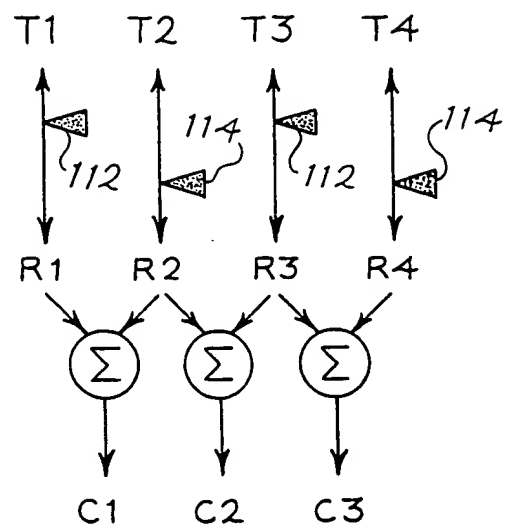

T1
T2
T3
T4
114
112
114
112
R1
R2
R3
R4
C1
C2
C3

Fig. 20

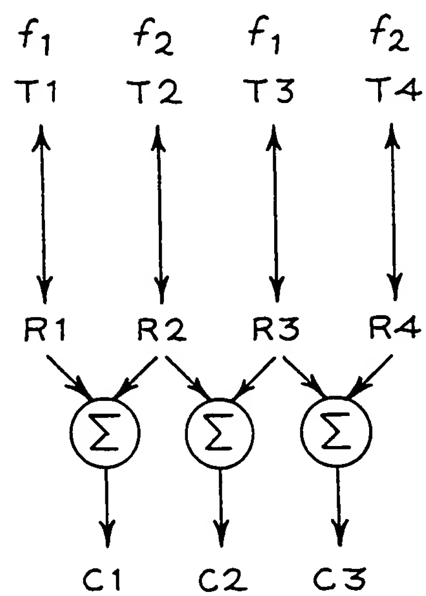

f_1
f_2
f_1
f_2
T1
T2
T3
T4
R1
R2
R3
R4
C1
C2
C3

Fig. 21

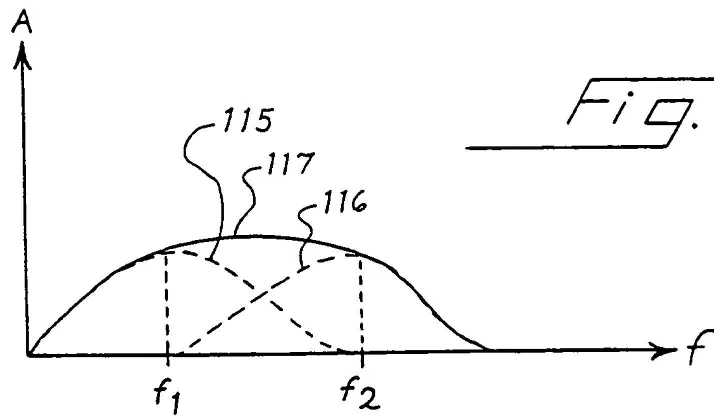
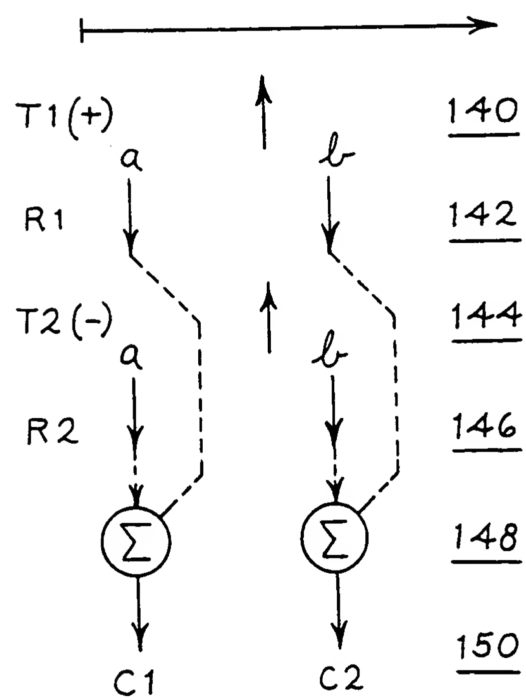

A
115
117
116
f
f_1
f_2

Fig. 22

Fig. 23


T1(+)
a
b
140
R1
142
T2(-)
a
b
144
R2
146
Σ
Σ
148
C1
C2
150

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/26879

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :A61B 8/00
US CL :600/447

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/625, 626; 367/7; 600/443, 447, 458

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
Search Terms: coheren?(2a)(sum? or combin?) and ultraso? and (image? or imaging)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A 5,617,862 A (COLE et al) 08 April 1997, col. 2 lines 43-67, col. 3 lines 54-57, and col. 13 lines 14-42.	1, 4-15, 17-26
Y	US 4,561,019 A (LIZZI et al) 24 December 1985, col. 3 lines 19-39.	1, 2, 7-11, 13-15, 19-26
Y	US 5,476,098 A (O'DONNELL) 19 December 1995, col. 7 lines 1-28.	1, 4-6, 8, 9-15, 17, 18, 20-26
Y	US 5,623,928 A (WRIGHT et al) 29 April 1997, col. 9 line 65 to col. 10 line 2, and col. 11 lines 58-64.	1-26
Y	US 5,632,277 A (CHAPMAN et al) 27 May 1997, entire document.	1-26

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 APRIL 1999	22 APR 1999

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/26879

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US 5,706,819 A (HWANG et al) 13 January 1998, entire document.	1-26
Y,P	US 5,833,613 A (AVERKIOU et al) 10 November 1998, entire document.	1-26